EASTERN REGION TECHNICAL ATTACHMENT
NO. 93-12B
DECEMBER 1993

A CASE STUDY OF THE 22 NOVEMBER 1992 OHIO VALLEY TORNADO OUTBREAK

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1. INTRODUCTION

From 21-23 November 1992, an unusually widespread late fall tornado outbreak occurred over the eastern third of the United States. Ninety-two tornadoes developed over the 3-day period. In the Ohio Valley, it was the most damaging late-season tornado outbreak ever recorded. Twenty tornadoes touched down over Indiana, Ohio, and Kentucky during this event (Hirt 1993).

This was not an atypical tornado outbreak given the time of year and geographical location. Many other late fall and winter tornado events have been recorded in the midwestern United States (Galway and Pearson 1981). Most of these cool season tornado events shared a common characteristic; the lack of diurnal heating was counteracted by processes on the synoptic scale, which sufficiently destabilized the atmosphere (Medlin 1990).

The purpose of this paper is to show that the synoptic and mesoscale features associated with the November 1992 tornado outbreak, were more indicative of a widespread springtime tornado outbreak than a cool season event. It will also be shown how the SHARP Workstation (Hart and Korotky 1991), and the ADAP mesoscale program, can be used to diagnose the potential for the severity and extent of thunderstorms. Information gained through the application of these tools, can be used to inform the public by issuing timely statements and warnings.

2. SYNOPTIC SCALE CONDITIONS

At 1200 UTC on 22 November, a 997 mb surface cyclone was centered over southern Missouri, with a well developed warm front extending through central Kentucky (Fig. 1). Abundant moisture, indicated by warm sector surface dewpoints at or above 60°F, was advected northward into the Ohio Valley by south winds in excess of 20 kt. By 1900 UTC, the surface cyclone pressure had lowered to 994 mb, and the center had moved into southern Illinois. The warm front had moved into central Indiana and Ohio, and the associated cold front was oriented north-south over central Kentucky and Tennessee (Fig. 2). Tornadoes have been associated with a strong synoptic scale storm system just southeast of the warm front-low center-cold front intersection (Miller 1972).

The synoptic system was negatively tilted and vertically stacked up to 300 mb. Strong wind fields were evident throughout the troposphere in the warm sector over the Tennessee and mid-Mississippi Valleys, with wind speeds of 50-60 kt at 850 mb, 60-80 kt at 500 mb, and 70-100 kt at 300 mb. Strong upper level diffluence was also present at the 500 and 300 mb levels (Figs. 3 and 4). Two jet streaks with wind speeds near 100 kt were also evident at 500 and 300 mb. One jet streak was located over Louisiana and Mississippi near the base of the trough, while the other extended from upper Michigan into northern Maine.

A well-developed dry slot was evident in the mid-levels of the atmosphere, as shown by the water vapor satellite imagery. The dry slot was also approaching an 850 mb theta-e ridge located over the Mississippi Valley (Fig. 5).

At 1200 UTC, in the low levels of the atmosphere, strong warm air advection was over the Tennessee and Ohio Valleys. A 65 kt jet maximum was apparent at 850 mb, extending from Mississippi into western Kentucky (Fig. 6). This transported $+10^\circ C$ dewpoints in the 850 mb layer from the Gulf Coast north into southern Illinois. Strong directional and speed convergence was indicated at 850 mb over Kentucky in the vicinity of the warm front, where 65 kt south winds converged with 5 kt east winds over southern Illinois and Indiana. Additionally, strong directional and speed shear was evident from the surface to 850 mb.

Johns and Doswell (1992) describe the typical combination of variables needed for a "synoptically evident" tornado outbreak. These include: a strong extratropical cyclone; a negatively tilted trough; significant upper-level diffluence ahead of the 500 mb trough; strong winds at all levels; strong veering of the wind with height; mid-level dry air intrusion; and sufficient instability. Such conditions only occur about 10 times a year, and typically during the spring in the Midwest. Anthony and Leftwich (1984) indicate that a mid-level dry intrusion overrunning low-level moisture sufficient to initiate convection is of particular importance when forecasting severe thunderstorm development, as long as a trigger mechanism is present to initiate the convection. Such a situation indicates the presence of convective instability.

As the synoptic situation evolved on 22 November, it was apparent that a tornado outbreak was possible in the Ohio Valley. The 1200 UTC dynamical model guidance from both the Nested Grid Model (NGM) and Limited-Area Fine Mesh Model (LFM), forecast the low pressure system to move northeast toward the Ohio Valley, and remain negatively tilted. The forecast trajectory of the storm placed the Ohio Valley under the left-front quadrant of the Mississippi jet streak, and under the right-rear quadrant of the southern Ontario jet streak. Such an upper-level jet streak pattern causes enhanced upper-level divergence, and in turn, considerable synoptic-scale ascent (Uccellini 1990). In addition, the lower and upper-level jets over the Mississippi and Tennessee Valleys were coupled, helping to convectively destabilize the atmosphere, and support the strong isallobaric wind flow over the Ohio Valley. These synoptic scale features would likely be sufficient to sustain severe convection (Uccellini and Johnson 1979). However, to narrow down the area where the tornadoes were most likely to develop, and how strong they might become, further mesoscale analysis was required.

3. SHARP ANALYSIS

By 1900 UTC on 22 November, a significant severe weather threat was evident across the Ohio Valley. In order to diagnose the stability and shear potential across the area, the SHARP workstation was utilized by forecasters at WSO Cincinnati (CVG). The most representative upstream sounding from 1200 UTC that morning was Nashville, Tennessee (BNA). Trajectories indicated that this sounding, particularly at lower levels, would most likely be representative of conditions in the Ohio Valley during the afternoon. Due to rapidly changing upper-air features, the Nashville sounding was extensively modified to represent the anticipated conditions. Based on the 1900 UTC surface observations and forecast upper-air features, the following modifications were made (Fig. 7):

1. Surface wind and storm motion were adjusted to the 1900 UTC surface weather observation at CVG: temperature 69°F, dewpoint 60°F, and wind 170° at 20 kt;

2. 500 mb temperature was lowered to -16°C;

3. 700 mb temperature was lowered to 0°C;

4. Temperature sounding from 700 - 500 mb was lowered 2 - 4°C in an attempt to simulate cold air advection; and the

5. 850 mb temperature left unchanged.

These modifications indicated that the potential existed for supercell thunderstorm and possible tornado development. Based on the observed storm motion from CVG radar, the storm relative helicity was calculated to be 418 $(m/s)^2$, which indicated the possibility of tornadoes with F2-F3 intensity (Davies-Jones et al. 1990). The Convective Available Potential Energy (CAPE) was calculated to be 1055 $(m/s)^2$, which is not considered particularly high. However, as Johns and Doswell (1990) indicate: "Instability may be important for supercell development only insofar as it is a factor in initiating and sustaining the updraft." With such high helicity values indicated on the modified sounding, it seemed likely that only marginal instability was needed to sustain supercells.

The 0000 UTC sounding from Dayton, Ohio (DAY) on 23 November, which was representative of the atmospheric conditions during the height of the outbreak, validated the assumptions made during the earlier modification of the Nashville sounding (Fig. 8). The lifted index was -5°C, with a 500 mb temperature of -16.9°C, confirming that the sounding had been destabilized by cold air advection aloft. In addition, considerable dry air intrusion had occurred in the mid levels from 700 - 500 mb.

When the observed storm motion from the tornadic supercells of that evening was input into the WSO DAY hodograph, the 0 to 3 km storm relative helicity was found to be 507 $(m/s)^2$. This exceeded the value obtained by using the Nashville sounding and was primarily due to the slight right movement of the supercells relative to the mean wind. Helicity values in this range are associated with violent (F4-F5) tornadoes (Davies-Jones et al. 1990).

4. ADAP UTILIZATION

The modified SHARP sounding was also used to modify instability (lifted index) outputs from ADAP (AFOS Data Analysis Programs). Assuming the lifted index on the modified sounding was correct, it was compared to the ADAP output for 500 mb lifted indices to determine areas where sufficient instability would be available for severe thunderstorm development.

Bothwell (1989) indicated that when significant cold air advection is occurring in the upper levels of the atmosphere, adjustments should be made to the ADAP output. On 22 November, the 1900 UTC surface-based lifted index output from ADAP for WSO CVG was -1°C (Fig. 9). However, as indicated earlier, a lifted index of -5°C was calculated by using the SHARP workstation given the extrapolated 1900 UTC conditions at WSO CVG. This indicated that the ADAP lifted index was about 4°C too high, and that a -4°C degree correction should have been applied to the lifted index values in the area of interest. After making these modifications, it was apparent that the atmosphere over much of southern Indiana, southern Ohio, and Kentucky was sufficiently unstable to support severe thunderstorm development.

Additional ADAP products identified areas where the potential for severe convection to develop ahead of the advancing cold front was high. Surface theta advection (Fig. 10), as well as surface moisture flux convergence (Figs. 11 and 12), indicated that the highest likelihood for severe thunderstorm development was over southern Indiana, extreme northern Kentucky, and extreme southwestern Ohio. Several studies, including Hirt (1982), have shown that a moisture convergence-divergence couplet enhances the potential for severe convection.

Following the Bothwell decision tree for ADAP products, two distinct areas of "extreme" severe weather potential were indicated over the Ohio Valley at 1900 UTC. One area, where the theta advection and moisture flux convergence was the most concentrated, was over extreme southern Indiana. The other threat area, associated with the greatest pressure falls and the synoptic low-pressure center, was over central Indiana (Figs. 13 and 14). It was in these two locations that the most damaging tornadoes occurred (Fig. 15).

5. RADAR DEPICTION OF SUPERCELLS

At 1800 UTC, thunderstorms began to develop rapidly along the Illinois-Indiana border in the dry wedge ahead of the surface cold front, just south of the surface low pressure system. The thunderstorms intensified as they moved northeast into central Indiana and quickly reached severe criteria. By 1903 UTC, the Cincinnati Weather Service Radar indicated a storm with supercell characteristics moving through central Indiana (Fig. 16). This possibly tornadic storm developed in an area of strong theta advection, and moved northeast along the southern edge of the greatest 3-hr pressure falls.

By 2039 UTC, isolated cells ahead of the main line of thunderstorms began to develop in the gradient between the surface moisture convergence center over south central Indiana, and the surface moisture divergence center over eastern Kentucky (Fig. 17). At 2131 UTC, a thunderstorm about 40 miles southwest of WSO CVG exhibited supercell characteristics (Fig. 18). By 2152 UTC, the strongest tornado (F4) of the event touched down from this supercell.

Based on the information obtained from SHARP, ADAP, meso, and synoptic scale analyses, appropriate statements and warnings were issued to warn of tornadic development. A Special Weather Statement and Radar Summary was issued by WSO CVG at 2051 UTC, with strong wording emphasizing the tornadic threat (Fig. 19). As the cells began to develop, calls were made to the county dispatch centers in the high-risk area, to alert officials of the increasing danger. When wind damage was reported in the vicinity of a supercell which developed ahead of the main line of thunderstorms, a tornado warning was issued about 5 minutes before the tornado actually touched down (Fig. 20).

6. SUMMARY AND CONCLUSION

In this study of the 22 November 1992 tornado outbreak in the Ohio Valley, it was shown that the synoptic scale environment actually mirrored a springtime tornadic situation. By modifying the appropriate representative sounding on the SHARP workstation, the likelihood of severe thunderstorms and violent tornadoes was forecast, and the proper statements and warnings were issued.

Applying the variables calculated by SHARP to the ADAP mesoscale output, the northern extent of the high-instability area was established, indicating that tornadoes might develop further north than originally indicated through the ADAP analysis alone. Furthermore, by monitoring ADAP products, especially surface pressure changes, surface moisture flux convergence, and surface theta advection, the most likely areas for supercell development and the subsequent tornadoes were isolated. Based on this information, timely and accurate weather statements and warnings were prepared to warn of the high probability of damaging tornado development.

The 22 November 1992 Ohio Valley tornadic outbreak illustrates the importance of using the various mesoscale forecast application programs (SHARP and ADAP) which are available at most Weather Service offices. Through the use of these tools, a forecaster can make better informed decisions on how to handle an evolving severe weather situation. They can also use this information to warn the public, and to fulfill the Weather Service mission to protect life and property.

ACKNOWLEDGMENTS

Special thanks goes to Steven Schurr (MIC WSO Wichita) for his detailed review of our paper, and for providing us with enhanced charts for the figures in this study. We also thank F. Julia Dian (WSO Cincinnati), Rusty Kapela (DMIC WSFO Cleveland), Jeff Waldstreicher (SOO WSO Binghamton), Richard Grumm (SOO WSO State College), and Stephan Kuhl (Eastern Region Headquarters, SSD) for their very helpful suggestions and comments concerning our analysis.

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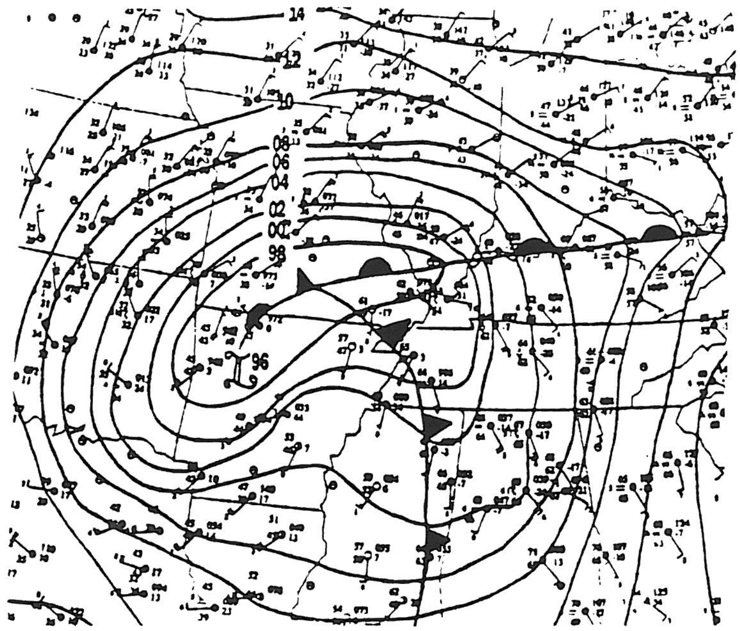


Figure 1. 1200 UTC, 22 November 1992 surface analysis.

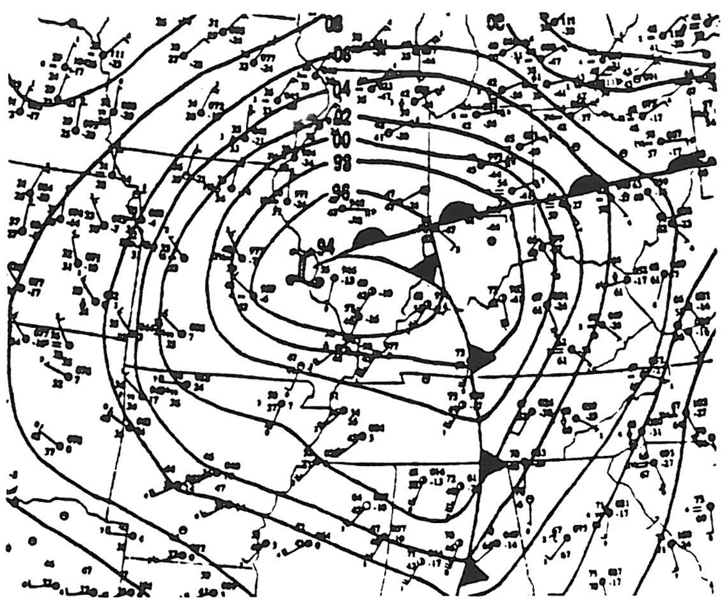


Figure 2. Same as Figure 1, except for 1900 UTC.

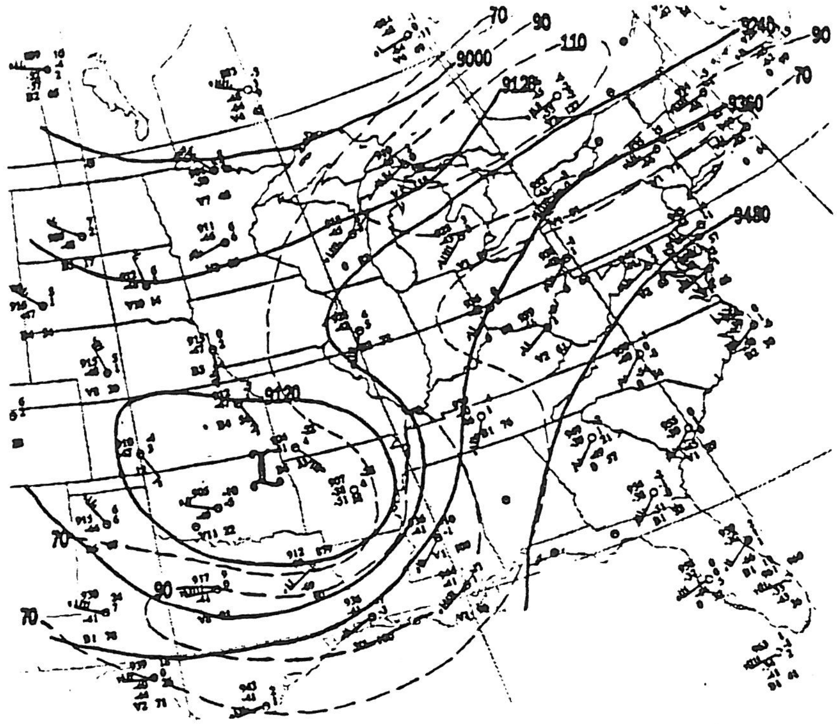


Figure 3. 1200 UTC, 300 mb analysis. Solid contours denote height (dm). Dashed contours denote wind speed (kt).

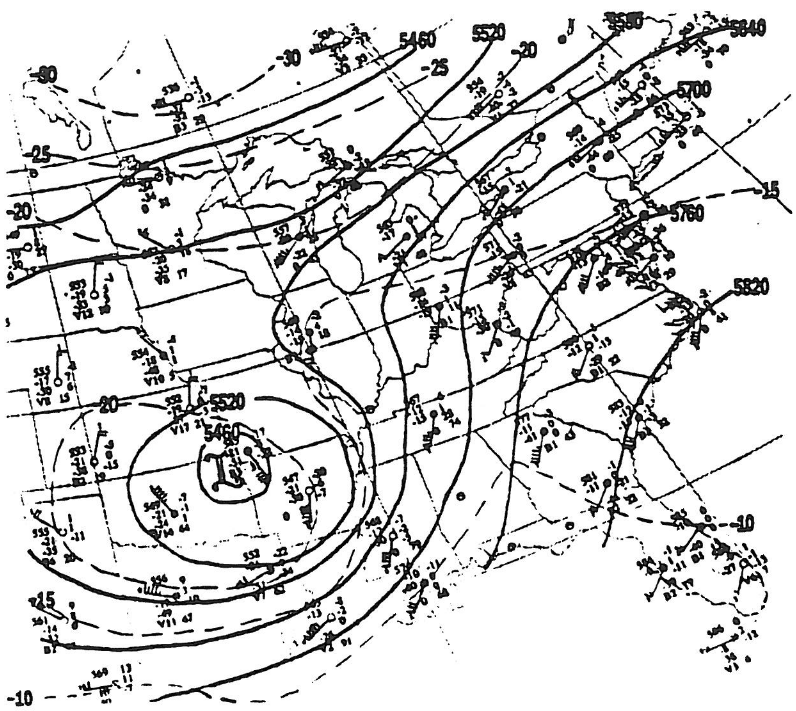


Figure 4. 1200 UTC, 500 mb analysis. Solid contours denote heights (m). Dashed contours denote temperature (°C).

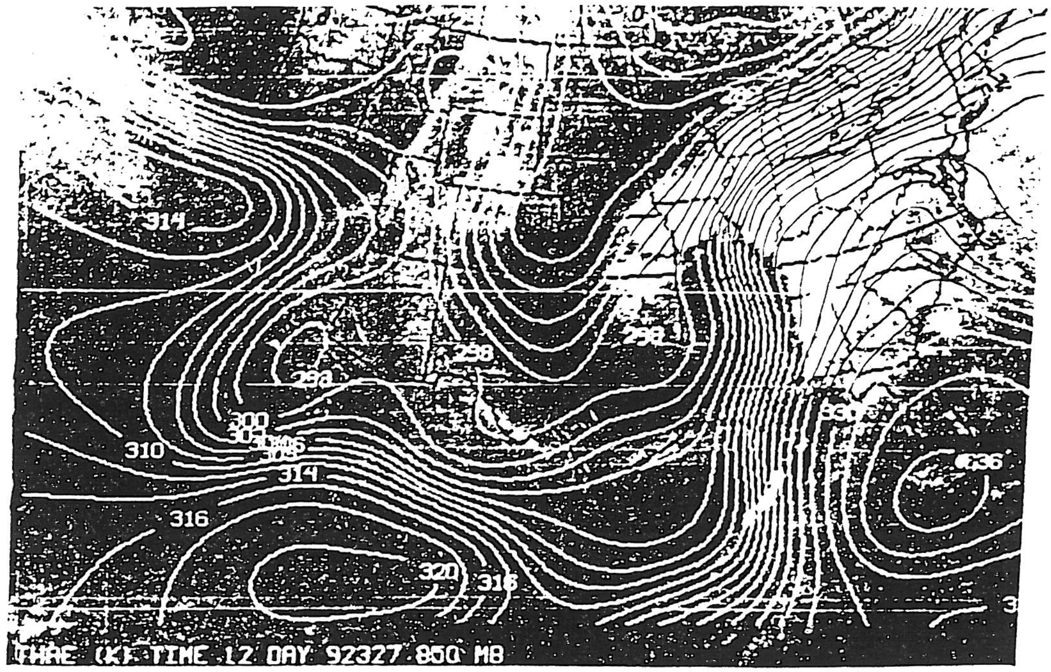


Figure 5. 1200 UTC, 6.7 μm water vapor satellite imagery and derived 850 mb Theta-E (K) analysis.

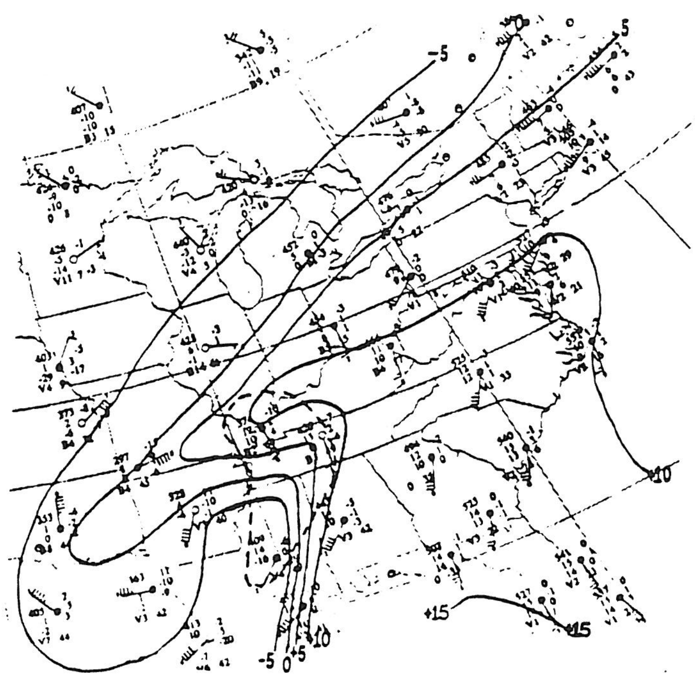
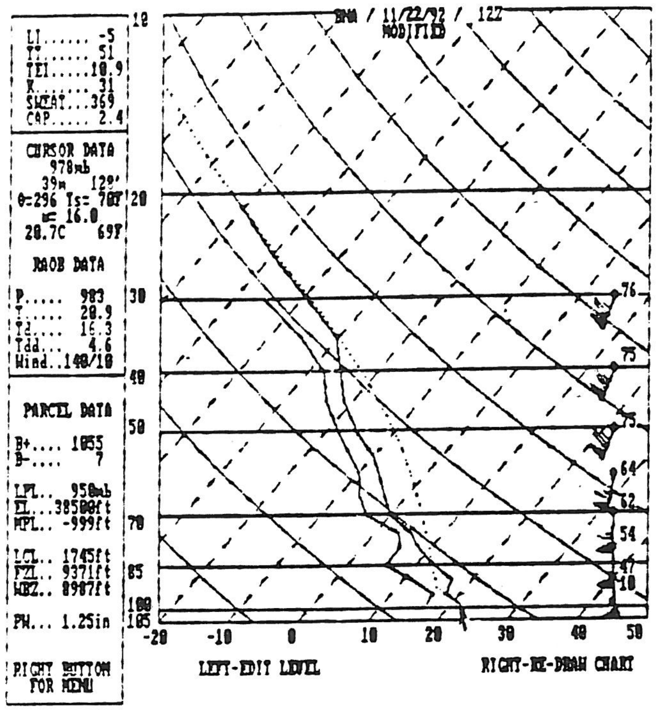


Figure 6. 1200 UTC, 850 mb analysis. Solid contours denote isodrosotherms (°C). Dashed contours denote the 50 kt isotach.



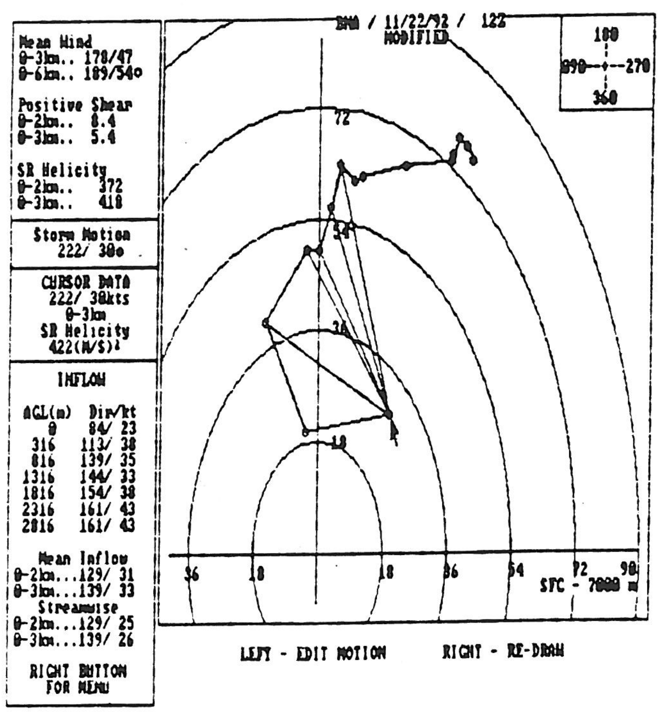


Figure 7. Modified Nashville (BNA) 1200 UTC, 22 November 1992 sounding and hodograph. From the SHARP Workstation (Hart and Korotky 1991).

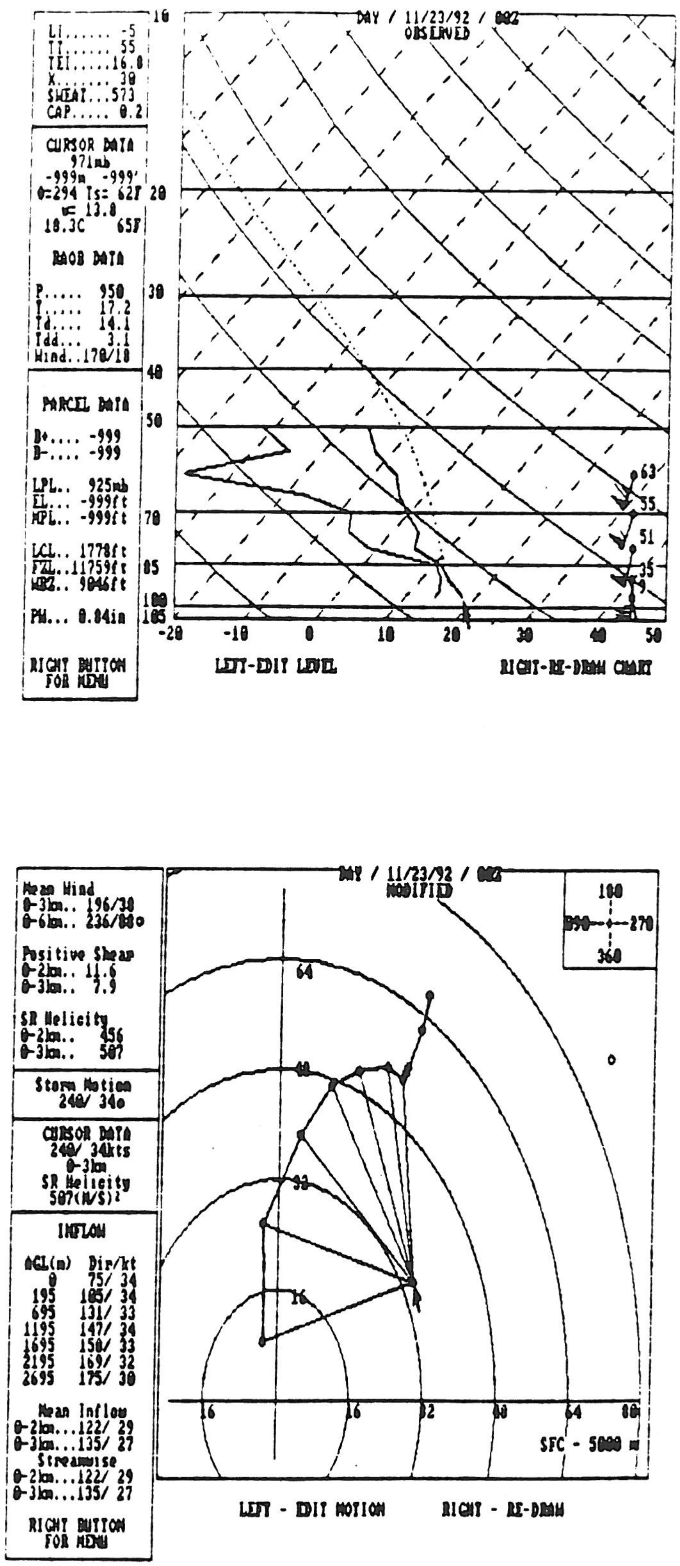


Figure 8. Modified Dayton (DAY) 0000 UTC, 23 November 1993 sounding and hodograph. From the SHARP Workstation (Hart and Korotky 1991).

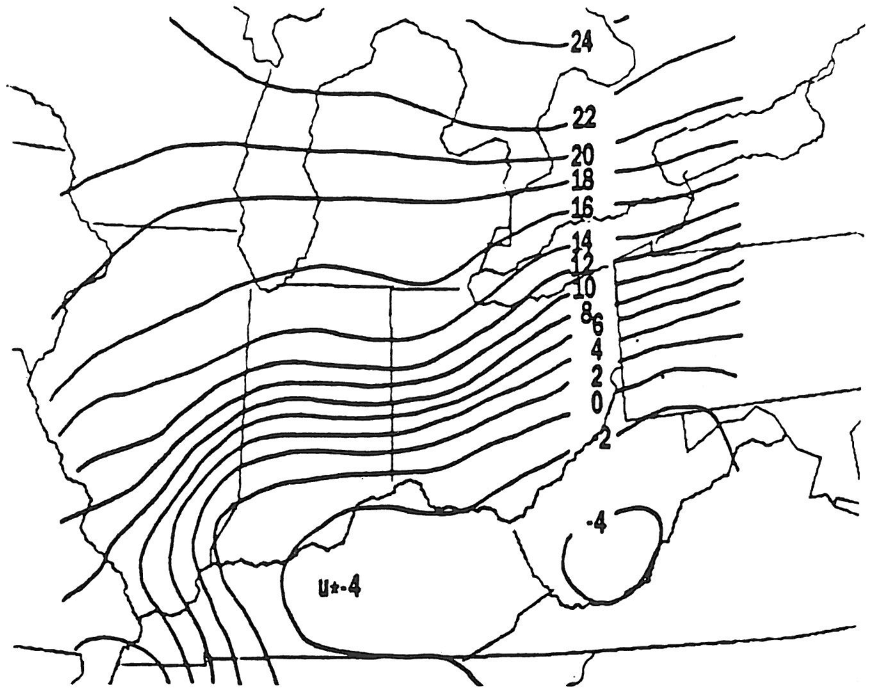


Figure 9. 1900 UTC, ADAP surface based LI analysis (˚C).

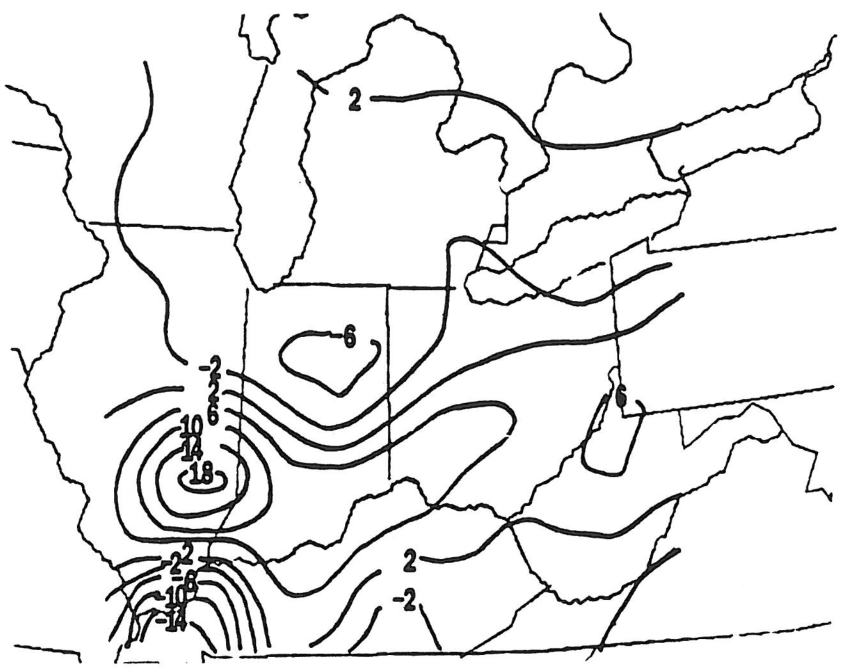


Figure 10. 1900 UTC, ADAP surface theta advection analysis (˚F/hr*10).

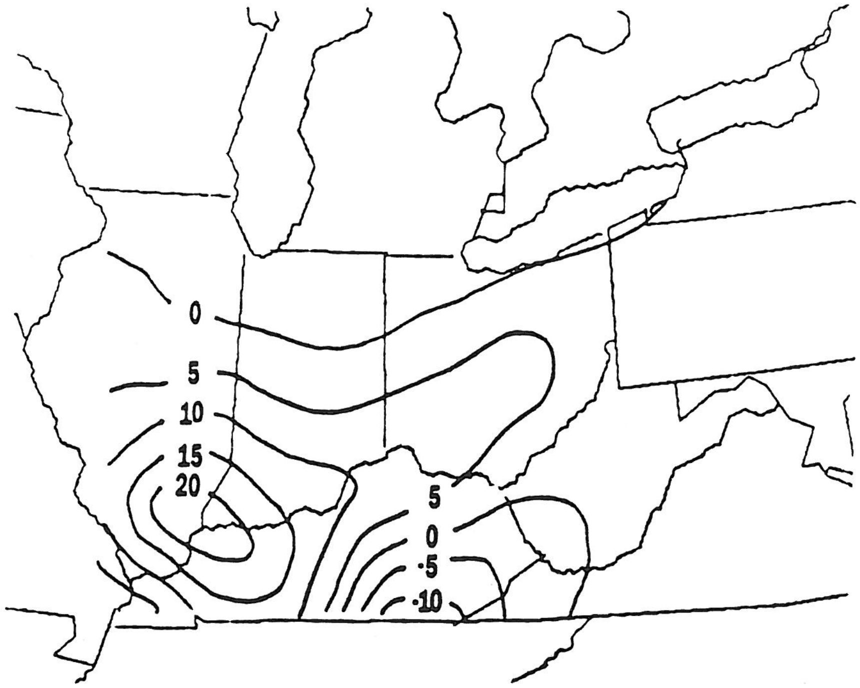


Figure 11. 1700 UTC, ADAP surface moisture flux convergence analysis (g/kg*(hr*10)).

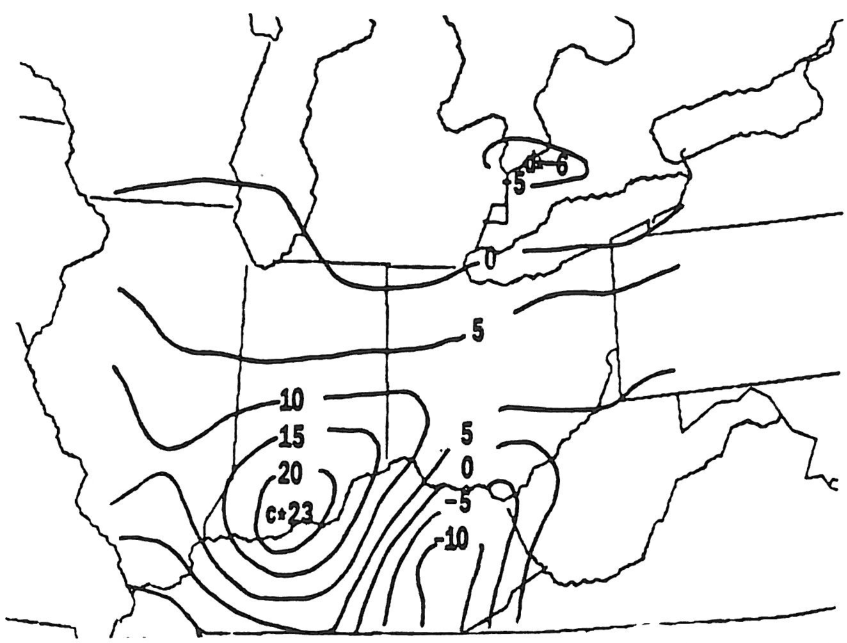


Figure 12. 2000 UTC, ADAP surface moisture flux convergence analysis (g/kg*(hr*10)).

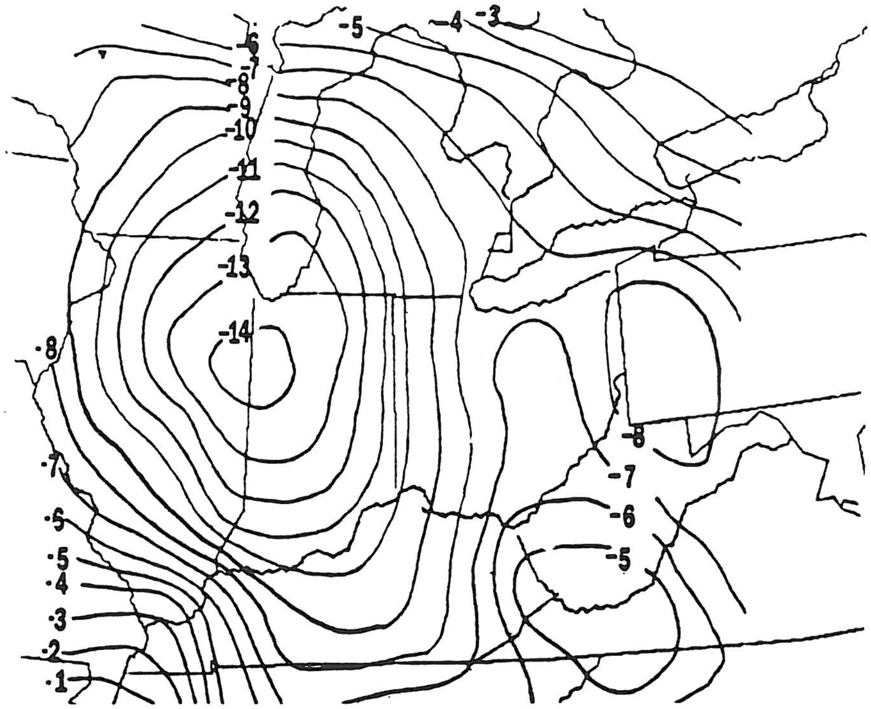


Figure 13. 1700-1900 UTC, ADAP surface pressure change analysis (hundredths of inches).

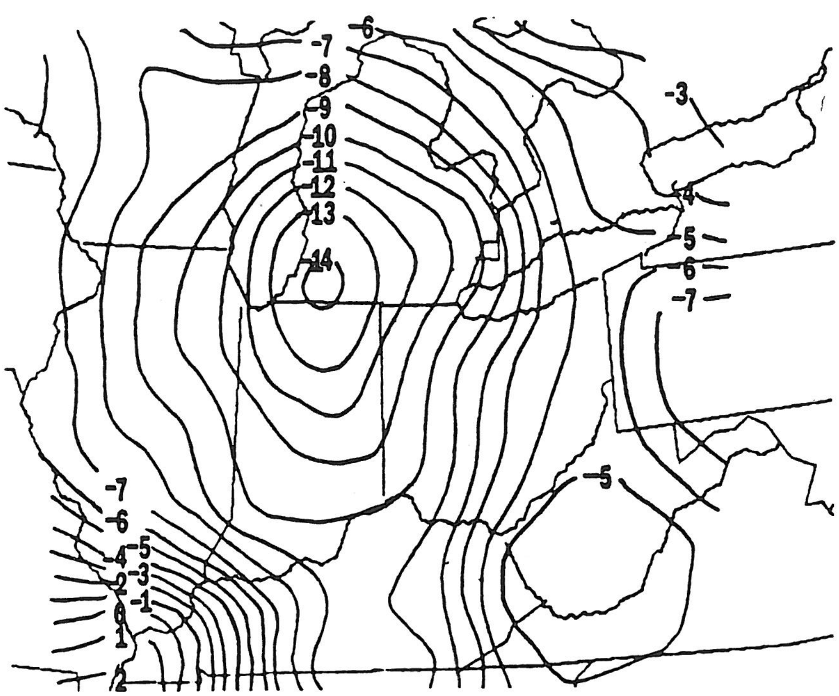


Figure 14. 1800-2000 UTC, ADAP surface pressure change analysis (hundredths of inches).

Figure 15. Tornado location and intensity on 22 November 1992 (from Hirt 1993).

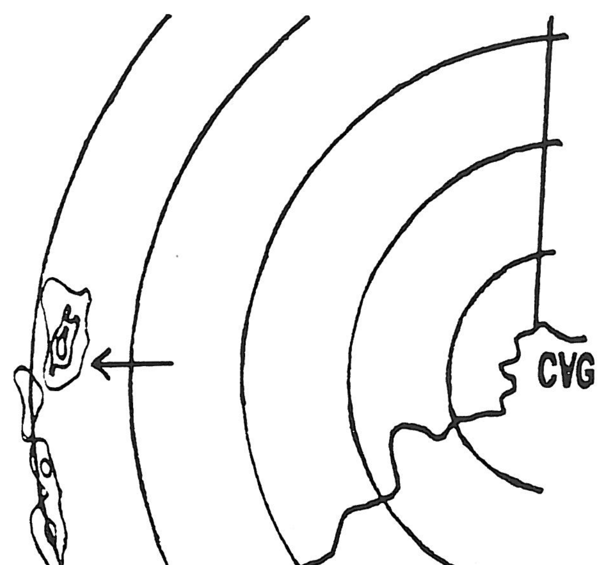


Figure 16. 1903 UTC, 22 November 1992, WSO CVG radar depiction. Contoured intensities denote DVIP levels 2, 3, and 5. Range rings are in 25 n mi. Storms with supercell characteristics are highlighted with arrows.

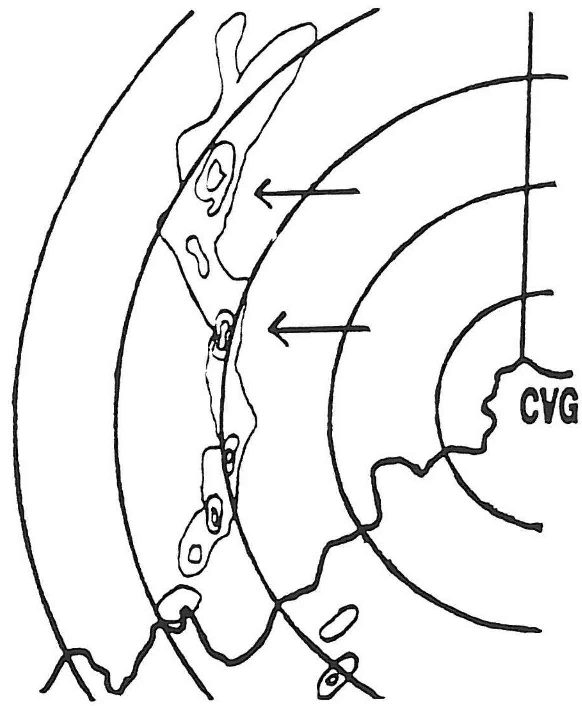


Figure 17. Same as figure 16, except for 2039 UTC.

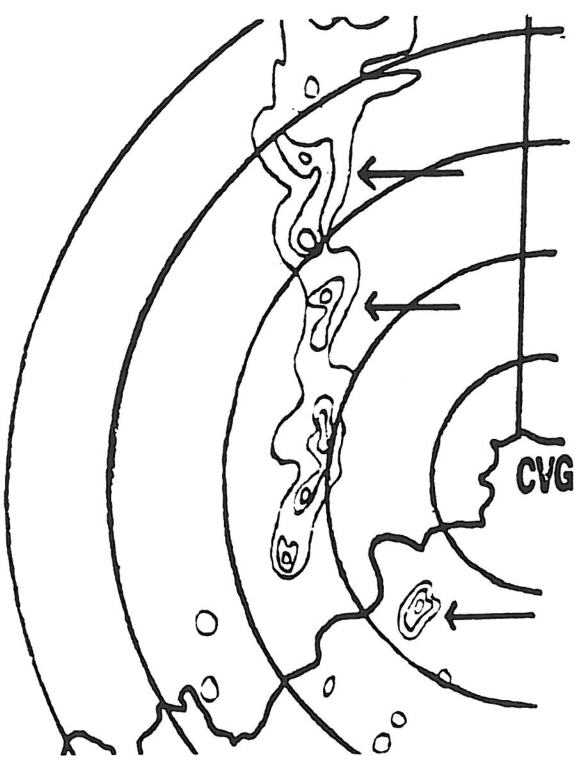


Figure 18. Same as figure 16, except for 2131 UTC.

NNNN>##<A
<ZCZC CLESPSCVG
TTAA00 KCVG 222053
OHZ008-INZ013-KYZ005-222230-

SPECIAL WEATHER STATEMENT AND RADAR SUMMARY
NATIONAL WEATHER SERVICE CINCINNATI OH
351 PM EST SUN NOV 22 1992

A TORNADO WATCH IS IN EFFECT FOR THE WESTERN HALF OF THE CINCINNATI TRISTATE UNTIL 900 PM EST. THIS WATCH INCLUDES MOST OF THE CINCINNATI METRO AREA.

A FLOOD WATCH IS ALSO IN EFFECT FOR SOUTHWEST OHIO TONIGHT.

AT 335 PM EST...A 15 MILE WIDE LINE OF THUNDERSTORMS...SOME OF WHICH WERE SEVERE...EXTENDED FROM 30 MILES NORTH OF INDIANAPOLIS TO 20 MILES WEST OF LOUISVILLE. TORNADOES AND DAMAGING WINDS HAVE BEEN REPORTED IN SOUTH CENTRAL INDIANA IN ASSOCIATION WITH THIS LINE.

THE LINE WAS MOVING EAST AT 30 MILES AN HOUR. IT WILL MOVE INTO SOUTHEAST INDIANA AFTER 430 PM EST...AND INTO THE CINCINNATI METRO AREA BY 530 PM EST.

THIS IS A POTENTIALLY DANGEROUS SITUATION. THE STORMS WILL HAVE THE POTENTIAL OF PRODUCING DAMAGING WINDS IN EXCESS OF 60 MILES AN HOUR...LARGE HAIL...AND POSSIBLY TORNADOES. PEOPLE IN THE CINCINNATI TRISTATE ARE URGED TO KEEP A CLOSE WATCH ON WEATHER CONDITIONS LATE THIS AFTERNOON AND EARLY THIS EVENING.

A REMINDER TO RESIDENTS OF HAMILTON COUNTY...BECAUSE A TORNADO WATCH IS IN EFFECT FOR CINCINNATI...THE OUTDOOR CIVIL DEFENSE SIRENS WILL SOUND IF EITHER A SEVERE THUNDERSTORM OR A TORNADO WARNING IS ISSUED. IF THE SIRENS SOUND...TAKE COVER IMMEDIATELY.

STAY TUNED TO NOAA WEATHER RADIO OR THE COMMERCIAL MEDIA FOR LATER STATEMENTS AND POSSIBLE WARNINGS.

PYTLAK

Figure 19. Special Weather Statement issued at 2053 UTC by WSO Cincinnati.

NNNN>##<A
<ZCZC CLETORCVG
TTAA00 KCVG 222148
KYC041-222215-

BULLETIN - EBS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE CINCINNATI OH
447 PM EST SUN NOV 22 1992

THE NATIONAL WEATHER SERVICE IN CINCINNATI HAS ISSUED A
TORNADO WARNING EFFECTIVE UNTIL 515 PM EST
FOR PEOPLE IN THE FOLLOWING COUNTY...

IN NORTH KENTUCKY...
...CARROLL

AT 438 PM EST WEATHER SERVICE RADAR SHOWED A POSSIBLE TORNADO ALONG THE OHIO RIVER ABOUT 10 MILES WEST OF CARROLL COUNTY KENTUCKY.

BARN DAMAGE HAS BEEN REPORTED WITH THIS STORM.

IF YOU ARE IN THE PATH OF THIS STORM TAKE SHELTER IMMEDIATELY. IF YOU ARE IN THE PATH OF A TORNADO...THE SAFEST PLACE IS A BASEMENT. GET UNDER A WORKBENCH OR PIECE OF STURDY FURNITURE. IF NO BASEMENT IS AVAILABLE...SEEK SHELTER IN AN INTERIOR ROOM SUCH AS A CLOSET ON THE LOWEST FLOOR. USE BLANKETS...PILLOWS...OR CUSHIONS TO COVER YOUR BODY. AVOID WINDOWS.

SAM

Figure 20. Tornado Warning issued at 2148 UTC by WSO Cincinnati.